Analysis and High-Resolution Modeling of Tropical Cyclogenesis During the TCS-08 and TPARC Field Campaign

PI: Tim Li
IPRC/SOEST, University of Hawaii at Manoa
1680 East-West Road, POST Building 409B
Honolulu, Hawaii 96822
Phone: (808) 956-9427, fax: (808) 956-9425, e-mail: timli@hawaii.edu

Co-PI: Melinda S. Peng
Naval Research Laboratory
Monterey CA 93943-5502
Phone: (831) 656-4704, fax: (831) 656-4769, e-mail: melinda.peng@nrlmry.navy.mil

Award Number: N000140810256

LONG-TERM GOAL

The long-term goal of this project is to improve the prediction of tropical cyclone (TC) genesis, structure and intensity changes through improved understanding of the fundamental mechanisms involved. The accurate prediction of TC genesis, structure and intensity changes is critical to Navy missions and civilian activities in coastal areas. Significant gains have been made in the TC track prediction over the past decades. The genesis and intensity forecast, however, has shown very little progress during the same period. A main factor contributing to the lack of skill in the prediction of TC genesis and intensity is the lack of observations prior to and during TC genesis and intensification periods and the inadequate understanding of physical mechanisms that control the cyclogenesis and intensity change. The TCS-08 and TPARC field campaign provide an unprecedented opportunity for us to gain the first-hand insight of observed characteristics of TC genesis in western Pacific and to compare them with high-resolution model simulations. By analyzing and assimilating these data, we intend to understand the physical mechanisms that involve the TC internal dynamic and thermodynamic processes, external forcing, and scale interactions. Only after thoroughly understanding these processes, can one be able to tackle the weaknesses in the current state-of-art weather forecast models.

OBJECTIVE

The objective of this project is to investigate the synoptic and climatic aspects of tropical cyclone (TC) genesis in the western North Pacific (WNP). On one hand, specific synoptic and dynamic processes through which an initial weak vortex (either mid-level or near-bottom vortex) develops into a TC will be investigated in a cloud-resolving model. On the other hand, the large-scale control of the Madden-Julian Oscillation (MJO) and El Nino-Southern Oscillation (ENSO) on TC genesis in the WNP will be examined. Additional effort is to conduct data assimilation using data collected from TCS-08

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2013**	2. REPORT TYPE	3. DATES COVERED **00-00-2013 to 00-00-2013**

4. TITLE AND SUBTITLE **Analysis and High-Resolution Modeling of Tropical Cyclogenesis During the TCS-08 and TPARC Field Campaign**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Hawaii at Manoa,IPRC/SOEST,1680 East-West Road, POST Building 409B,Honolulu,HI,96822**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

observational campaign. We will examine how the cyclogenesis forecast may be significantly improved with a better description of the dynamic and thermodynamic precursor signals.

APPROACH

For understanding the synoptic and dynamic aspects of cyclogenesis, a multi-nested WRF model (with 2 km resolution in the innermost mesh) will be used to simulate both idealized and real-case cyclogenesis events. Through the diagnosis of the model outputs, we intend to understand the common and different development characteristics associated with cyclogenesis in an environment with a near bottom vortex (EBV) and an environment with a mid-level vortex (EMV). The genesis time for each model run will be defined based on an objective way. A concept of the cyclogenesis efficiency (which is related to the initial environmental dynamic and thermodynamic conditions) will be introduced. A number of idealized experiments will be designed to illustrate the relative importance of initial column-integrated absolute vorticity, PBL parameters, surface fluxes, and vertically integrated relative humidity in determining the TC genesis efficiency.

For understanding the climatic aspect of cyclogenesis, various statistical tools such as the wavenumber-frequency analysis, lagged regression analysis, and composite analysis methods will be applied to understand the role of the MJO and ENSO in determining the intraseasonal and interannual variability of TC activity in the WNP.

For the data assimilation task, WRF 3DVar assimilation system will be employed. Because the TCS-08 campaign provides variety types of in-situ data at irregular spatial and temporal intervals, we intend to construct a high-resolution regular-grid reanalysis product that combines in-situ observations (such as ELDORA radar, Doppler wind lidar, dropsondes and driftsondes) with satellite remote sensing products.

WORK COMPLETED

A paper that studied tropical cyclone development under vertical shear and dry air intrusion was published in *Journal of Atmospheric Sciences*. A paper about the bimodal character of cyclone climatology in Bay of Bengal was published in *J. Climate*. A paper entitled "ENSO-phase dependent TD and MRG wave activity in the western North Pacific" was published in *Climate Dynamics.* A manuscript entitled "Characteristics of tropical cyclone genesis in the western North Pacific during the developing and decaying phases of two types of El Niño" was accepted by *J. Tropical Meteorology*. A paper entitled "Tropical Cyclogenesis in the Western North Pacific as Revealed by the 2008-2009 YOTC data" was published in *Wea. Forecasting.*

RESULTS

1. Effects of vertical shears and mid-level dry air on tropical cyclone developments

A set of idealized experiments using WRF are designed to investigate the impacts of mid-level dry air layer, a vertical shear, and their combined effects, on tropical cyclone (TC) developments. We design the following numerical experiments. In the control experiment (NOSH_CTL), we exclude both the dry air intrusion and the vertical shear. The initial fields contain a weak symmetric cyclonic vortex, with a maximum surface wind speed of 8 ms^{-1} at a radius of 150 km and the wind speed decreasing

with height. This control experiment represents TC development under the favorable conditions with no vertical shear or a dry air layer. The second experiment (NOSH_DRY) is designed to examine the impact of the mid-level dry air layer with no mean flow. The specification of dry air layer follows Braun et al. (2012). A dry air layer is specified between 850 and 650 hPa, in which RH is set as 25% to mimic the dry SAL. This dry air layer is embedded at all grid points 150-km north of the initial vortex center. Four additional experiments with different vertical shears are designed. WSH_CTL and ESH_CTL are to examine the impact of different vertical shear profiles on TC development without mid-level dry air layer. In the flow with an easterly (westerly) wind shear, the zonal wind decreases (increases) linearly from 4 (-4 ms^{-1}) at the surface to -4 (4ms^{-1}) at the top of the model, and zero wind speed at 500 hPa. WSH_DRY and ESH_DRY have the same shear as in WSH_CTL and ESH_CTL, but with dry air located to the north of the vortex.

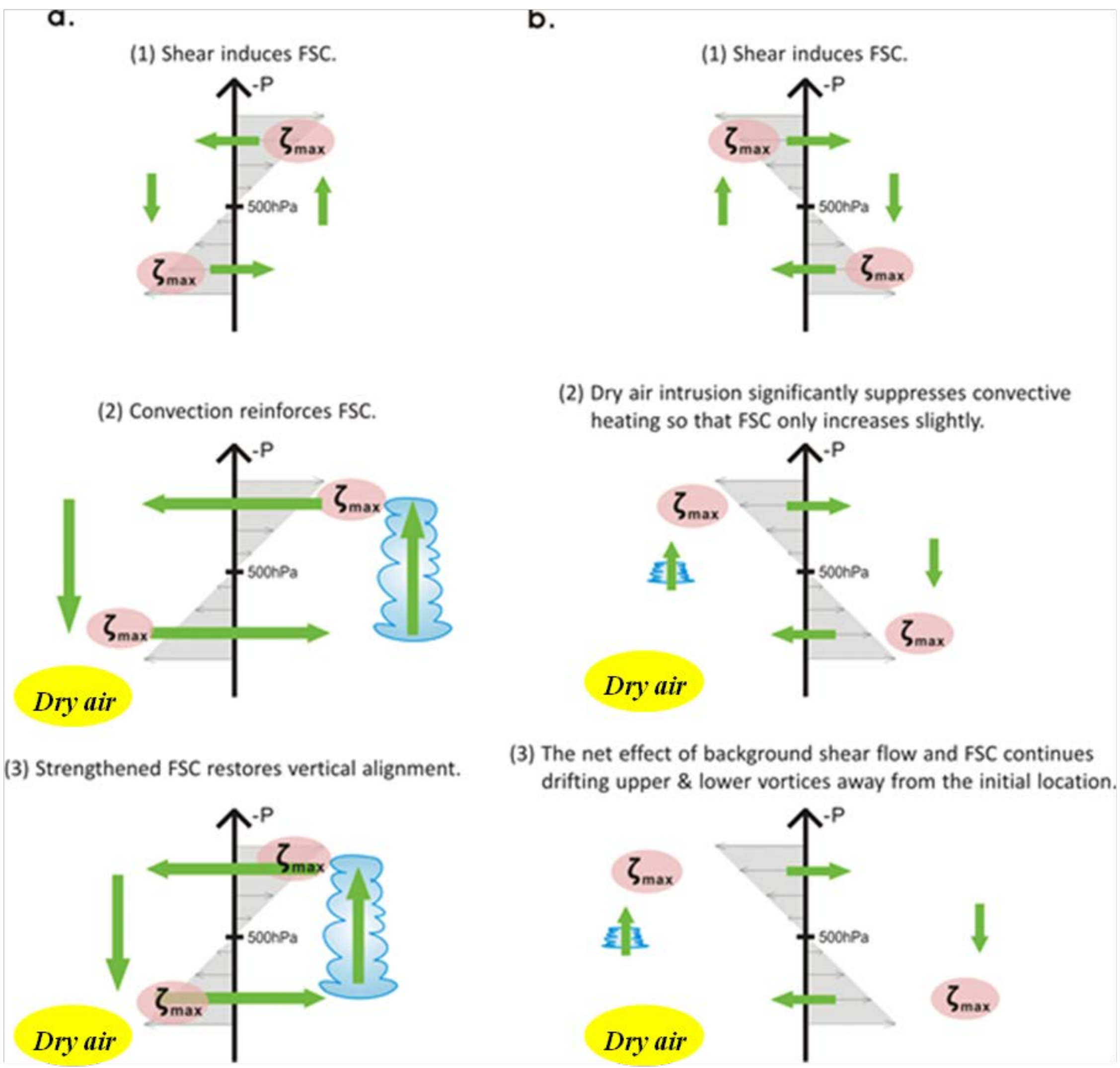

Fig. 1 Schematic summarizing the effect of FSC on the impact of vertical shear: (a) how the shear induced FSC is established and how the convection reinforced FSC helps restore the vertical alignment in WSH_DRY and (b) how the FSC fails to offset the shear advective effect due to dry air intrusion in ESH_DRY.

Numerical simulations show that without the existence of a mid-level dry air, the easterly and westerly shear effects on a TC development are quite similar. However, in the presence of dry air, the intensification rate and the final TC state in WSH_DRY and ESH_DRY are very different from each other. In ESH_DRY, dry air is quickly wrapped into the vortex core region during the first 48 hours, and covers almost the entire core region by 96 hour. As a consequence, there is no TC genesis. In contrast, in WSH_DRY, a TC is able to form, even though its intensification rate is weaker than that in WSH_CTL. The results indicate that the mid-level dry air imposed is very effective in hindering the storm development under the shear condition. The impact of dry air is highly sensitive to the orientation of vertical shear.

Why does the dry air allow the TC development under the westerly shear but not the easterly shear? We hypothesize that the difference is attributed to the relative location of dry air in relevance to the downshear quadrant. When it is placed to the right (left) of the downshear region, the dry air is easier (not easier) to be advected into the convective region of the FSC. Figure 1 contains two schematic diagrams showing how the westerly and easterly shear affect the FSC and the subsequent vertical alignment process in the case when the dry air is placed initially to the north of the vortex center. In the westerly shear case (Fig. 1a), a cyclonic vortex that is initially vertically aligned will gradually tilt eastward with height due to vorticity advection. While the upper-level vortex shifts eastward from the original position, the lower-level vortex shifts westward. According to the omega equation, positive (negative) vorticity advection to the east of the upper (lower) level vorticity maximum would lead to ascending motion. Likewise, the differential vorticity advection will lead to descending motion to the west side of the low-level circulations. Thus a secondary circulation (green arrows) forms, with maximum vertical velocity near 500 hPa. With the aid of the moist process, the ascending branch of the FSC is strengthened due to condensational heating associated with enhanced convection. Therefore, the FSC is reinforced to help overcome the shear-induced drifting and “restore” the vertical alignment.

How does the ESH_DRY differ from the WSH_DRY? Recalled that in our model configurations, the dry air layer is place to the north of the vortex center. Due to the combination of cyclonic circulation of the vortex and the mean flow, the dry air originally located north of the vortex will be quickly advected to the west side of the circulation. As a result, there is an asymmetry of the moisture distribution in the zonal direction with dryer air to the west and moister air to the east. While the FSC for the easterly shear (upper panel in Fig. 1b) is exactly opposite to the one for the westerly shear (upper panel in Fig. 1a), the dry-air zonal asymmetric distribution comes to play in the next step. As illustrated in the middle panel of Fig. 1b for ESH_DRY, with the dryer air existing in region where the upward branch of the FSC resides, the FSC in ESH_DRY lacks convective mechanism for enhancing itself as seen in the WSH_DRY case. Therefore, the parted upper-level vortex due to the shear continues drifting away from the low-level vortex.

This study indicates the importance of dry air and vertical shear orientations in determining the impact. The background vertical shear causes the tilting of an initially vertically aligned vortex. The shear forces a secondary circulation (FSC) with ascent (descent) in the downshear (up-shear) flank. Hence, convection tends to be favored on the downshear side. The FSC reinforced by the convective heating may overcome the shear-induced drifting and “restore” the vertical alignment. When dry air is located in the downshear right quadrant of the initial vortex, the dry advection by cyclonic circulation brings the dry air to the downshear side and suppresses moist convection therein. Such a process disrupts the “restoring” mechanism associated with the FSC and thus inhibits TC development. The sensitivity

experiments show that, for a fixed dry air condition, a marked difference occurs in TC development between an easterly and a westerly shear background.

2. Tropical cyclogenesis in the western North Pacific as revealed by the 2008-2009 YOTC data
The Year of Tropical Convection (YOTC) high-resolution global reanalysis data were analyzed to reveal precursor synoptic-scale disturbances related to tropical cyclone (TC) genesis in the western North Pacific (WNP) during 2008-2009 typhoon seasons. A time filtering is applied to the data to isolate synoptic (3-10-day), quasi-biweekly (10-20-day) and intraseasonal (20-90-day) time-scale components. The results show that four types of precursor synoptic disturbances associated with TC genesis can be identified in the YOTC data. They are 1) Rossby wave trains associated with pre-existing TC energy dispersion (TCED) (24%), 2) synoptic wave trains (SWT) unrelated to TCED (32%), 3) easterly waves (EW) (16%), and 4) a combination of either TCED-EW or SWT-EW (24%). The percentage of identifiable genesis events is higher than previous analyses.

Most of the genesis events occurred when atmospheric quasi-biweekly and intraseasonal oscillations are in an active phase, suggesting a large-scale control of low frequency oscillations on TC formation in the WNP. For genesis events associated with SWT and EW, maximum vorticity was confined in the lower troposphere. During the formation of Jangmi (2008), maximum Rossby wave energy dispersion appeared in middle troposphere. This differs from other TCED cases in which energy dispersion is strongest at low level. As a result, the mid-level vortex as a result of Rossby wave energy dispersion grew faster during the initial development stage of Jangmi.

3. Dependence of tropical wave activity on ENSO phase
The three-dimensional structure and evolution characteristics of tropical depression (TD) and mixed Rossby-gravity wave (MRG) type disturbances in the tropical western North Pacific (WNP) during El Niño and La Niña summers are investigated based on observational and reanalysis data. A clear MRG-to-TD transition was observed during El Niño summers while such a transition is unclear during La Niña summers. The vertical structure of the TD-MRG waves appears equivalent barotropic during El Niño but becomes tilted eastward with height during La Niña. The diagnosis of barotropic energy conversion shows that both the rotational and divergent components of the background flow change associated with ENSO are responsible for energy conversion from the mean flow to the TD-MRG perturbations.

A further examination of the pure MRG mode shows that its intensity does not vary between El Niño and La Niña while its phase speed does. A faster (slower) westward propagation speed during La Niña (El Niña) is attributed to enhanced (reduced) mean easterlies in the western equatorial Pacific. The heating associated with the MRG wave appears more anti-symmetric during La Niña than during El Niño. In contrast to the MRG waves, the amplitude of the TD waves depends greatly on the ENSO phase. The enhanced (suppressed) TD disturbances during El Niño (La Niña) is attributed to greater (less) barotropic energy conversion associated with the background flow change. The vertical structure of the TD waves appears quasi-barotropic in the geopotential height field but baroclinic in the divergence field.

IMPACT/APPLICATIONS

The investigation of dependence of TC genesis efficiency on initial vortex structure and large-scale factors that control TC genesis and the construction of the typhoon reanalysis product may improve our current understanding of cyclogenesis dynamics and promote a more skillful prediction of TC genesis and intensity change.

TRANSITIONS

Results from this study may lead to improvement of TC prediction in the NOGAPS and COAMPS models. The TC dynamic initialization scheme used in the typhoon reanalysis effort may be transitioned into a 6.4 project.

RELATED PROJECTS

This project is complimentary to the ONR funding entitled "Initialization of tropical cyclone structure for operational application" in which we applied TC dynamic initialization strategy to the Observation System Simulation Experiment (OSSE) in an idealized setting using the WRF model and real-case TC forecast during 2009-2010 using NRL COAMPS-TC model. Knowledge gained from this project will help improve the current operational model TC initialization.

PUBLICATIONS

The following are papers published in 2013 that are fully or partially supported by this ONR grant:

Chung, P.-H., and T. Li, 2013: Characteristics of tropical cyclone genesis in the western North Pacific during the developing and decaying phases of two types of El Niño, *Journal of Tropical Meteorology*, in press.

Ge, X., T. Li, and M. Peng, 2013: Effects of vertical shears and mid-level dry air on tropical cyclone developments. *J. Atmos. Sci.*, in press.

Li, Z., W. Yu, T. Li, V. S. N. Murty, and F. Tangang, 2013: Bimodal character of cyclone climatology in Bay of Bengal modulated by monsoon seasonal cycle, *J. Climate*, **26** (3), 1033-1046.

Wu, Liang, Z. Wen, T. Li, and R. Huang, 2013: ENSO-phase dependent TD and MRG wave activity in the western North Pacific. *Climate Dynamics*, in press.

Xu, Y.-M., T. Li, and M. Peng, 2013: Tropical Cyclogenesis in the Western North Pacific as Revealed by the 2008-2009 YOTC data. *Wea. Forecasting*, 28, 1038-1056.

Manuscript in preparation:

Bi, M.-Y., T. Li, X. Shen, and M. Peng, 2013: Role of atmospheric low-frequency oscillations in causing Megi's (2010) sharp northward turning.